The Pharma Innovation Journal 2022; 11(3): 1811-1816

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(3): 1811-1816

www.thepharmajournal.com
Received: 08-01-2022
Accepted: 17-02-2022

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Biofertilizer as prospective input for sustainable agriculture in India: A review

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Abstract
Farmers are now facing a reduction in agricultural crop yield, due to the infertility of soils and poor farming. The application of chemical fertilizers distresses soil fertility and also human health. Inappropriate use of chemical fertilizer leads to the rapid decline in production levels in most parts of the world, and hence requires the necessary standards of good cultivation practice. Biofertilizers and biopesticides have been used in recent years by farmers worldwide to preserve natural soil conditions. Bio fertilizer, a replacement for chemical fertilizer, is cost-effective and prevents environmental contamination to the atmosphere, and is a source of renewable energy. In contrast to chemical fertilizers, biofertilizers are cost-effective and a source of renewable energy that preserves long-term soil fertility. The use of biofertilizers is, therefore, inevitable to increase the earth's productivity. A low-input scheme is feasible to achieve farm sustainability through the use of biological and organic fertilizers. This study investigates the use of microbial inoculants as biofertilizers to increase crop production. Despite being cost-effective and eco-friendly, several constraints including unreliable supplies and the absence of proper quality control limit the application or implementation of the technology. Extensive research is required to identify more suitable strains, develop better production technologies and quality control measures for the wide commercialization of biofertilizers. The development of biofertilizers with multi-crop growth-promoting activities is most important for sustainable global agriculture.

Keywords: Bio fertilizers, Microorganisms soil fertility, crop production

Introduction
The population in India as well as in the World is increasing day by day and it puts considering the pressure on the agricultural lands and other resources to fulfill the need for food of this huge population. Chemical fertilizers and pesticide dependence in conventional agriculture have increased, due to the significant growth of the human population and food demands. Soil quality deterioration reversed biodiversity, increased water, and air pollution, and human health has also created excess use of chemical fertilizer (Swapna, *et al*. 2013) [43]. The agriculture ecosystem, soil fertility, and cultivated crop growth get affected, due to excessive usage of chemical pesticides (Rahman *et al*., 2018) [34]. In the case of Asia, it has been estimated that each 1% increment in crop productivity leads to0.48% reduction in the number of poor people (Thirtle *et al*., 2003) [45]; while, in India, 1% rise in agricultural value-added per hectare declines 0.4% poverty in the short run and 1.9% in the long run due to indirect effects of lower food prices and higher wages (Ravallion and Datt, 1996) [35]. Therefore, at present, the most challenging issue is to increase the production of food from the rapidly shrinking per-capita agricultural land (Bhattacharyya, 2009; Mazid and Khan, 2014) [4, 23]. Generally, in conventional agriculture there are two major inputs necessary for crop production, *viz*., fertilizer and pesticide; in other words, it can be said that fertilizer is food and pesticide is medicine for plants (Muraleedharan *et al*., 2010) [27]. Though the production in India was remarkably high during periods of the Green Revolution, poverty still remains as it was concentrated mainly in favorable areas. As a consequence of that, the growth of yield became downwards in addition to high utilization of chemical fertilizers caused poor soil health due to lack of organic matter, loss of inherent fertility (Mahajan and Gupta, 2009; Khare and Arora, 2015) [16, 15] by affecting soil microflora and fauna (Gupta and Singh, 2008) [13]. Even it also impaired the health of human beings and animals (Gupta and Singh, 2006; Khare and Arora, 2015) [12, 15]. Moreover, plants cannot uptake all the nutrients applied through chemical fertilizers (Bhardwaj *et al*., 2014) [3] so, some amount of nutrients are either fixed in the soil or leached out and ultimately mixed with water bodies (Mahdi *et al*., 2010) [18].

In order to make agriculture sustainable, it is necessary to implement a balanced and reasonable use of nutrients that are cost-effective and ecofriendly (Venkataraman and Shanmugasundaram, 1992; Mahdi *et al.*, 2010) [46, 18]; in that case, biofertilizer could be a suitable option (Pindi and Satyanarayana, 2012; Borkar, 2015) [33, 6]. Now, the Government of India has also taken a stride to harness the full potential of the available biofertilizers by introducing them along with chemical fertilizers to the farmers (Ghosh, 2004) [11]. Beneficial microorganisms utilized in biofertilizers improve microflora, soil health, plant growth, plant disease control, and protect the plant from pests (Deepak, *et al*. 2014) [9]. The present contest is to provide sufficient food to this increasing population.

Biofertilizer

Biofertilizer', also named as 'micro inoculants' (Arora *et al*., 2010) [2], was derived from the retrenchment of the term 'biological fertilizer'; with biological, denoting the use of living organism or it can be defined as a product containing living microorganisms that colonize in rhizosphere accompanying interior of the plant and stimulates growth by increasing the accessibility and uptake of mineral nutrients to the host plant (Vessey, 2003; Malusá *et al*., 2012; Malusá and Vassilev, 2014) [47, 19]. Biofertilizers can fix atmospheric nitrogen through the process of biological nitrogen fixation (BNF) and solubilize plant nutrients like phosphates, potash; in addition, it also stimulates plant growth through the synthesis of different growth-promoting substances and has C: N ratio of 20:1 indicating its stability (Wani *et al*., 2013; Borkar, 2015) [48, 6]. Biofertilizers can be categorized into five groups based on their nature and activity as follows (Table 1): Recently, the potash mobilizers like Frateuri Laurentia, zinc and sulfur solubilizers like Thiobacillus sp., and manganese solubilizer fungal culture like *Penicillium citrinum* have also been identified for commercial operations (Borkar, 2015) [6]. History of biofertilizer use in India, a systematic study on biofertilizers was started by N. V. Joshi in 1920. Rhizobium was the first isolated from various cultivated legumes and this was followed by extensive research by Ganguly, Sarkaria, and Madhok on the physiology of the nodule bacteria along with its inoculation for better crop production (Panda, 2011) [31]. The milestones in research, production, and promotion of biofertilizer in India. Now, Rhizobium and Blue-Green Algae (BGA) can be considered as established biofertilizers whereas Azolla, Azospirillum, and Azotobacter are at an intermediate stage (Panda, 2011) [31].

Practical significance of biofertilizer

Biofertilizers make nutrients available that are naturally abundant in soil and atmosphere to plants. Various field studies have demonstrated these to be effective and cheap inputs, free from any environmental hazards (Ghosh, 2004; Sahoo *et al.*, 2014; Borkar, 2015) [11, 3, 6]. In a nutshell, it provides "ecofriendly" organic agro-input which has the ability to convert nutritionally important elements from unavailable to available form through biological processes (Vessey, 2003) [47]. So, it can be expected to reduce the use of chemical fertilizers and pesticides by introducing biofertilizers (Subashini *et al*., 2007) [42]. The microorganisms in biofertilizers reestablish the natural nutrient cycle, maintain optimum nutrient levels in soil and also increase soil organic matter content as a result healthy plants can be grown while upholding sustainability and fertility of the soil (Singh *et al.*, 2011; Sinha *et al*., 2014; Shelat *et al.*, 2017) [40, 41, 39]. Therefore, they are extremely advantageous in enriching soil fertility and fulfilling plant nutrient requirements by supplying organic nutrients. Besides accessing nutrients for current intake as well as residual, different biofertilizers provide growth-promoting factors to plants through secretion of different vitamins, phytohormones (Revillas *et al.,* 2000; Abd El-Fattah *et al.,* 2013) [36, 1] and by successfully facilitating composting and controlling attack of pest and soil-borne diseases (Board, 2004; Sinha *et al.,* 2014) [5, 41]. It not only saves chemical fertilizers but also helps in its effective utilization and results in higher yield rates (Ghosh, 2004) [11]. Dryland agriculture constitutes a very large part of the agricultural area in India including the majority of the poor people and more than 90% of coarse cereals, 80% of groundnut, and 85% of pulses come from these regions (Ghosh, 2004) [11]. Dryland agriculture is characterized by low productivity, unpredictable climatic swings, and low dosage of chemical fertilizers and in this situation, biofertilizers, particularly Rhizobium, could be a bridge between removals and additions to soil nutrients where farmers can scarcely afford costly inputs (Das *et al.,* 2015) [8]. It is an established fact that due to fixation in acidic and alkaline soils, the efficiency of phosphate fertilizers is very low (15-20%) and unfortunately both soil types are prevailing in India (Board, 2004) [5]. On that account, the inoculation of phosphate solubilizing bacteria in soils is needed to restore and maintain the effective microbial populations for solubilization of chemically fixed phosphorus as well as the availability of other macro and micronutrients to harvest good sustainable yield of various crops (Mahdi *et al.,* 2010) [18].

Marketed biofertilizers in India

The following types of microorganisms as biofertilizers are available to the farmers in India: Nitrogen fixer, e.g. Rhizobium, Bradyrhizobium, Azospirillum, Azotobacter, Acetobacter, Azolla and BGA.

Phosphorus solubilizer, e.g. Bacillus, Pseudomonas and Aspergillus.

Phosphate mobilizer, e.g. VA-mycorrhiza (VAM) like Glomus.

K-solubilizer, e.g. *Frateuria aurantia*.

Silicate solubilzer, e.g. *Thiobacillus thiooxidans*.

Plant growth promoting biofertilizers, e.g. Pseudomonas sp. (Muraleedharan, 2010; Mishra and Arora, 2016) [27, 25].

Application of biofertilizers

Seed treatment

The seeds are homogeneously mixed with slurry of inoculant and then shade dried for 30 minutes. The shade dried seeds are sown within 24 hours. One packet of the inoculant (200 g) is sufficient to treat 10 kg of seeds.

Seedling root dip

Highly used for transplanted crops. Two packets of the inoculants are mixed in 40 liters of water. The root portion of the seedlings is dipped in the mixture for 5 to 10 minutes and then transplanted.

Main field application

Four packets of the inoculants are mixed with 20 kg of dried and powdered farm yard manure (FYM) and then broadcasted in the main field just before transplanting.

Set treatment

This method is recommended generally for treating sugarcane sets. Culture suspension is prepared by mixing 1 kg (5 packets) of bio-fertilizer in 40-50 liters of water and kept immersed in the suspension for 30 minutes. The cut pieces are dried in shade for some time before planting after imbibing of suspension. For set treatment, the ratio of biofertilizer to water is approximately1:50.

Production scenario in India

The estimated annual requirement of Rhizobium inoculum varies from 1,250 to 15,000t (Panda, 2011) [31]. The highest requirements of biofertilizers can be quantified through an over-simplified approach multiplying the total legume area by dosage per hectare; therefore if 25% of the area is annually treated, 3750t inoculums are needed for 30 MHA and the present production is about one-fourth of this. Year-wise (2008-09 to 2014-15) production in India has been listed in table 3. Based on crop area in India, the present requirement of biofertilizers is around 5,50,000 metric tonnes and there is an ample potential to increase it to 50,000-60,000 tons by 2020 (Pindi and Satyanarayana, 2012) [33]; however, the total production in our country is much less than requirement which points out the inevitability of increase in biofertilizer production. Now, the government of India is boosting the biofertilizer industries by providing subsidies to a maximum of 20 lakh rupees and awarding a national productivity award to the efficient biofertilizer production unit (Borkar, 2015) [6]. Agro Industries Corporation has the maximum production capacity which is followed by State Agriculture Departments, National Biofertilizers Development Centers, State Agricultural universities, and private sectors (Pindi and Satyanarayana, 2012) [33]. In organic farming the use of biofertilizers came into picture, which contains living microbes and when used for the plants, seeds, soil and populate the rhizosphere and encourage the plant growth by enhancing nutrient flow to the plant (Malusá *et al*.2014) [19].

Reasons behind little popularization of biofertilizer in India

Despite the multiple advantages of biofertilizers in agricultural production, several constraints at different levels i.e. from the production unit to farmers' field are there for making it less popular in India.

Production and distribution level

Generally, the activity of microorganisms are location and crop-specific so, strains selected for particular areas as well as crops should have good adaptability for this specific location and some qualities like competitive ability over other strains for nodulation of the host, N-fixing ability, potentiality to colonize and survive in adverse physical conditions (Panda, 2013) [32]. Some biofertilizer production units do not have sufficient technically well-qualified microbiologists or skilled persons who can make available high-quality biofertilizers rather depend on more non-skilled laborers working on a contract basis that leads to substandard biofertilizers (Mahdi *et al.*, 2010; Mathur *et al.*, 2010; Motghare and Gauraha, 2012) [18, 22, 26]. In addition, the non-availability of good quality peat in India has also headed to the development of alternative carriers like lignite, charcoal, etc. which are mostly used unsterilized (Borkar, 2015; Panda, 2013) [6, 32]. Most studies suggest that biofertilizers, sold in markets are contaminated and have a low count of microorganisms. Generally, producers do not pay attention to the host-specific strains and as a result, biofertilizers cannot express their potentiality (Mazid and Khan, 2014; Motghare and Gauraha, 2012) [23, 26]. Indian Standard Institute (ISI) specifications are recently available only for Rhizobium and Azotobacter; specification for Azospirillum and phosphobacteria have been formulated. Till now, there is no regulatory action for the production of biofertilizers (Mazid and Khan, 2014) [24]. Storage and distribution level Field level. Most of the farmers in India do not have enough perception of the use of biofertilizers. Similarly, a low level of acceptance of it at farmers' level is due to slow response as compared to chemical fertilizers. Some biofertilizers are crop as well as location-specific; therefore its efficacy does not remain the same at different locations due to differences in agro-climatic conditions and soil edaphic factors (Panda, 2013) [32]. In addition, there is no facility for foretasting and also no extension and propaganda of biofertilizers is being undertaken on large scale (Borkar, 2015) [6]. Moreover, the activities of microorganisms vary with the chemical properties of soil so, highly acidic as well as saline soils adversely affect the population of introduced biofertilizers (Fierer and Jackson, 2006) [10]. Sometimes in soils where P availability is less, the nitrogen-fixing biofertilizer does not function effectively (Khare and Arora, 2015) [15]. Therefore, soil amendments and chemical fertilization are essential in these situations.

Market level

Marketing of biofertilizers is troublesome as the product contains living organisms with restricted shelf life (Motghare and Gauraha, 2012) [26], only six months in powder form as a result, it is difficult under Indian conditions to transport, store and distribute the material in time. Besides this, there is no standardization in packing, labeling, and prices of biofertilizers (Das *et al.*, 2015) [8]. Sometimes, when packets arrive in villages, they are either spoiled or overdated; therefore, they become useless because organisms contained in biofertilizers die very quickly (Borkar, 2015) [6]. Furthermore, different state governments sometimes provide subsidies up to 50% of the sales but the manner of subsidization is rather unsystematic even in many cases discrimination and manipulation in subsidizing lead to a lot of intra industry variation in prices (Ghosh, 2004) [11].

Liquid biofertilizers: A step forward to biofertilizer technology

Liquid biofertilizers are suspension containing desired microorganisms and special cell protectants or chemicals that encourage the formation of latent spores or cysts for longer shelf life and tolerance to adverse environments (Hegde, 2008). The advantages of liquid biofertilizers over powder-based are that microorganisms have a longer shelf life up to 2 years, generally, they circumvent the effect of high temperature, maintain high cfu more than 109 ml-1upto 12 months, and better survive on seeds and soil, in addition, liquid biofertilizers are easy to use, handling and storage by farmers, the dosage is ten times less than that of powder form, it can be packed in different volumes and save carrier materials (Verma *et al.*, 2011; Borkar, 2015) [44, 6]. Biofertilizers have a potential role in sustainable agriculture;

these can be used along with chemical fertilizers to enhance soil fertility and crop yield. In India, farmers' especially marginal farmers can get more profit from the same size of land by using biofertilizers instead of the application of chemical fertilizers alone. However, most farmers are not aware of it; therefore, to popularize this technology training should be provided to the farmers and this can be done through demonstration trials on the cultivator's fields. In this case, extension workers would play an important role. Moreover, more research is needed to identify crop and location-specific microbial strains with higher efficacy. The government should introduce strict laws and policies against the quality of biofertilizers so that farmers can get benefits from this technology.

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Table 1: Different groups of biofertilizers

Sl. No.	Groups	Examples
		Nitrogen (N2) fixing Biofertilizers
1.	Free-living	Azotobacter, Clostridium, Anabaena, Nostoc
2.	Symbiotic	Rhizobium, Frankia, Anabaena azollae
3.	Associative Symbiotic	Azospirillum
		P-Solubilizing Biofertilizers
1.	Bacteria	Bacillus megaterium var. phosphaticum, Bacillus circulans, Pseudomonas striata
2.	Fung	Penicillium sp., Aspergillus awamori
		P-Mobilizing Biofertilizers
1.	Arbuscular mycorrhiza	Glomus sp., Gigaspora sp., Acaulospora sp. Scutellospora sp., Sclerocystis sp.
2.	Ectomycorrhiza	Laccaria sp., Pisolithus sp., Boletus sp., Amanita sp.
3.	Orchid mycorrhiza	Rhizoctonia solani
		Biofertilizers for Micro nutrients
1.	Silicate and zinc solubilizers	Bacillus sp.
		Plant Growth Promoting Rhizobacteria
1.	Pseudomonas	Pseudomonas fluorescens

Table 2: Some milestones in research, production and promotion of biofertilizer in India

Year	Events
1920	First study on Legume-Rhizobium symbiosis by N. V. Joshi.
1934	Earliest documented production of Rhizobium inoculant by M. R. Madho
1939	Discovery of nitrogen fixation by Blue Green Algea (BGA) in rice field by P. K. Dey.
1939	Report on performance of Azotobacter in rice soil by B. N. Uppal.
1956	First commercial production of biofertilizer.
1957	Study on solubilization of phosphate by microorganisms by Sen and Pal.
1958	First attempt to standardize quality of legume inoculant by A. Sankaran
1960	First isolation of new non-symbiotic N-fixing organism Derxiagummosa in the world by P. K. Dey and R. Bhattacharyya.
1964	Spurt in demand of biofertilizer for soybean particularly in Madhya Pradesh.
1968	All India Pulse Improvement Project and Soybean Project set up by ICAR where Rhizobium study got priority.
1969	Use of Indian peat as carrier reported by V. Iswaran.
1975	Coal as alternate carrier to peat reported by J. N. Dube
1976	Indian Standard Specification for Rhizobium
1977	Use of ISI mark for Rhizobium.
1979	Initiation of All India Coordinated Project on BNF.
1979	ISI standard for Azotobacter inoculant.
1983	Setting up of National Project on Development and use of Biofertilizer by Ministry of Agriculture, Govt. of India.
1985	First National Productivity award on Biofertilizer.
1988	Setting up of National Facility Centre for BGA at IARI

Table 3: Recommendations of different Bio-fertilizer for various crops

Biofertlizer	Recommended Crops
Rizobium	Pluses, Oilseeds, Fodders
Azospirillum	Rice, Wheat, millets, maize, sorghum, sugarcane
Azotobactor	Rice, Wheat, millets, other cereals, cotton, vegetables, sunflower, mustered, flowers
Azolla	Submerged rice with maximum temperature
Blue Green algae	Submerged rice
PSM	All crops

Table 4: Major inoculation groups with inoculant and host plants (Ponmurugan and Gopi, 2006) [9]

Cross inoculation Group	Rhizobium species	Host Legume
Pea group	R. leguminosarum	Pea, sweet pea
Alfalfa group	R. meliloti	Sweet clover
Clover group	R. trifoli	Clover / berseem
Bean group	R. phaseoli	All beans
Soybean group	Bradyrhizobium japonicum	Lupins
Cowpea group	Rhizobium sp.	Cowpea, arhar, urd, moong and groundnut

Market level

Marketing of biofertilizers is troublesome as the product contains living organisms with restricted shelf life (Motghare and Gauraha, 2012) [26], only six months in powder form as a result, it is difficult under Indian conditions to transport, store and distribute the material in time. Besides this, there is no standardization in packing, labeling, and prices of biofertilizers (Das *et al.,* 2015) [8]. Sometimes, when packets arrive in villages, they are either spoiled or overdated; therefore, they become useless because organisms contained in biofertilizers die very quickly (Borkar, 2015) [6]. Furthermore, different state governments sometimes. Successful introduction of biofertilizers in farmers' fields is still limited to certain crops and locations, either because of environmental or biological factors i.e. soil Rhizobium-plant relationship (Panda, 2013) [32]. As biofertilizers are live microorganisms, usually die or loss their activity in case of temperature fluctuation. Bio-fertilisers of microbial origin can be a good option for sustaining productivity with more environment-friendly and integrated nutrient management approach (Mazid *et al*. 2014) [24].

Conclusions

Biofertilizers based on microbial inoculants are attractive because they act in fixing nitrogen, phosphate, sulfate, potassium, zinc, and solubilize nutrients and enhance plant growth by hormonal action or antibiosis and decomposing organic residues. Plant rein forcers and phytostimulators can be used by plants to improve their growth when insufficient quantities of nitrogens are present. Moreover, they emerged from the soil and appeared to be competent in the rhizosphere. Plant growth-promoting rhizobacteria with numerous activities, such as nitrogen fixation, phytohormone production, micro-and macro-mineral solubilization, enzymes production, or fungicidal compounds of antibiotics synthesis. They also improve and maintain the soil rhizosphere biologically by microbes, such as bacteria, fungi, algae, and actinomycetes. This review discusses the idea of single or consortiums have multiple activities, such as nitrogen-fixing, phosphate, sulfate, and zinc solubilization, through enzyme and acid production. The effect of microorganisms as biofertilizers and the role of plant growth by rendering them as tolerant to pests and to improve the crop health and food safety.

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